Searches for 1st and 2nd generation LQ in 4 fb^{-1}: status and plans

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Physics at CDF: LeptoQuarks

- **Leptoquarks (LQ)** are hypothetical particles which appear in many SM extensions to explain **symmetry between leptons and quarks**
  - SU(5) GUT model
  - superstring-inspired models
  - 'colour' SU(4) Pati-Salam model
  - composite models
  - technicolor

•LQs are **coupled to both leptons and quarks** and carry SU(3) color, fractional electric charge, baryon (B) and lepton (L) numbers

•**LQs can have**:

–spin 0 (scalar)

•couplings fixed, i.e., no free parameters

•Isotropic decay

–spin 1 (vector)

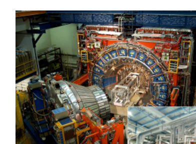
•anomalous magnetic (k_G) and electric quadrupole (λ_G) model-dependent couplings

–Yang-Mills coupling: $k_G = \lambda_G = 0$

–Minimal coupling: $K_G = 1$, $\lambda_G = 0$

–Decay amplitude proportional to $(1 + \cos\theta^*)^2$

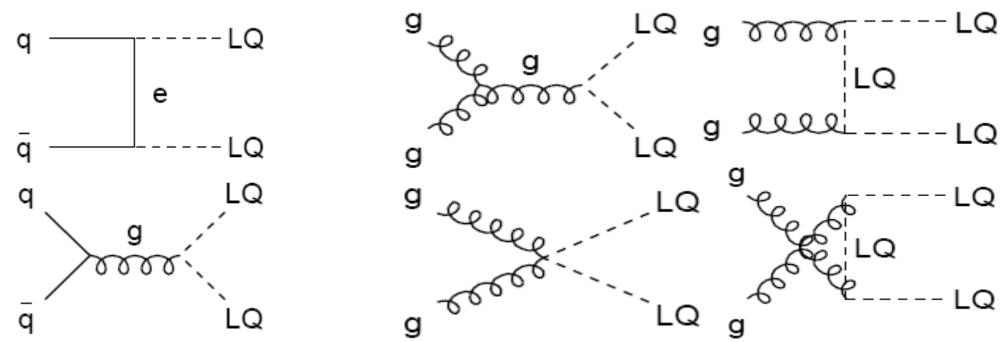
- **Experimental evidence searched:**
  - indirectly: LQ-induced 4-fermion interactions
  - directly: production cross sections at collider experiments



LQ at Hadron Colliders

- **Pair production**
  - Practically independent of Yukawa coupling λ (only g-LQ-LQ vertex)
  - Depends mainly on LQ mass

$q\bar{q} \to LQ\ LQ$ $\quad$ $gg \to LQ\ LQ$



Decay

- Each generation can decay into 3 final states: β = Br (LQ→lq)

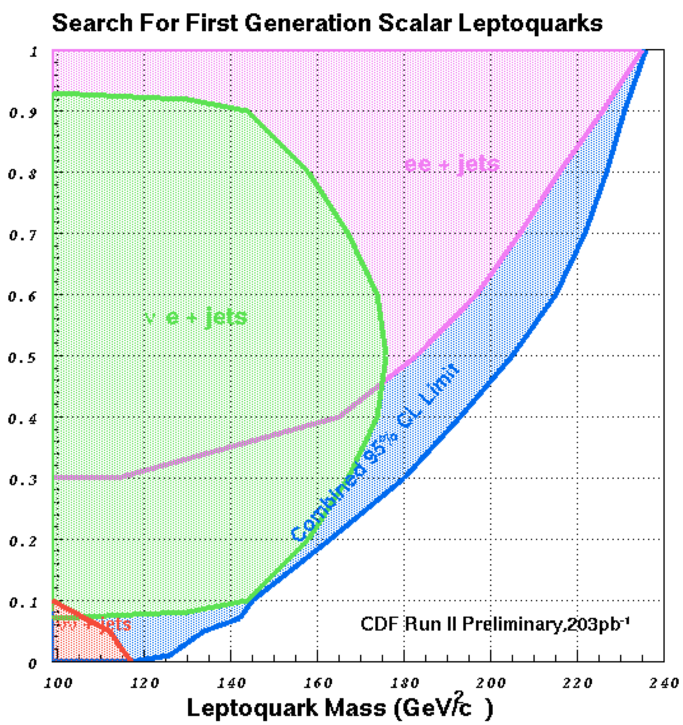
Exclusive to the Tevatron

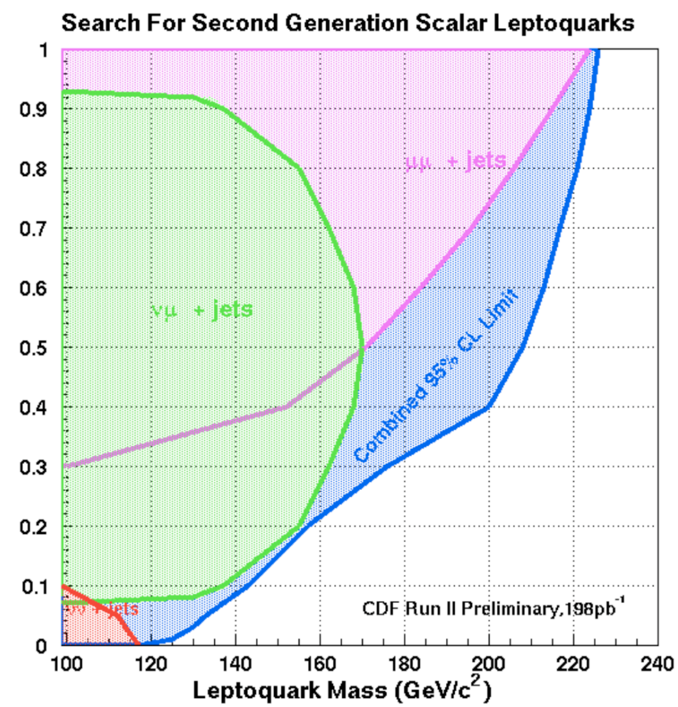
	1^{st} Generation	2^{nd} Generation	3^{rd} Generation
$\beta = 1$	$LQ\,\overline{LQ} \to e^- e^+ q\bar{q}$	$LQ\,\overline{LQ} \to \mu^+ \mu^- q\bar{q}$	$LQ\,\overline{LQ} \to \tau^+ \tau^- q\bar{q}$
$\beta = 0.5$	$LQ\,\overline{LQ} \to e^{\pm} \nu_e q_i q_j$	$LQ\,\overline{LQ} \to \mu^{\pm} \nu_{\mu} q_i q_j$	$LQ\,\overline{LQ} \to \tau^{\pm} \nu\, q_i q_j$
$\beta = 0$	$LQ\,\overline{LQ} \to \nu_e \nu_e q\bar{q}$	$LQ\,\overline{LQ} \to \nu_{\mu} \nu_{\mu} q\bar{q}$	$LQ\,\overline{LQ} \to \nu_{\tau} \nu_{\tau} q\bar{q}$

LQ at CDF

Tufts has been the primary institutions doing LQ searches in RunII:

- 1st generation, eeqq, eνqq + combined result (Simona -PhysRevD72 2005)
- 2nd generation:$\mu\mu$qq,$\mu\nu$qq + combined result (Dan Ryan-Simona PhysRevD73 2006)
- 3rd generation:$\tau\tau$qq (leptonic taus, Hao Sun thesis, never blessed)

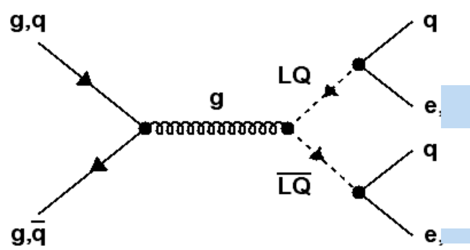




Analysis strategy

- Counting experiment:
  - We basically count how many events we observe in our sample which are consistent with LQ production and its irreducible background
    - If we observe a number of events which is consistent with the SM background expectation we will say that no LQ signal is observed an a 95% CL limit on the production cross section will be placed
    - If we observe more events than SM prediction, we will have found new physics …
    - We define a set of cuts that we place on the sample in order to enhance the possibility of observing signal while at the same time reducing as much as possible the background component.

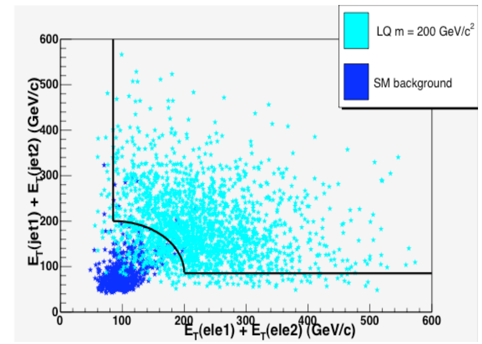
Search for LQ in dileptons + jets (I)

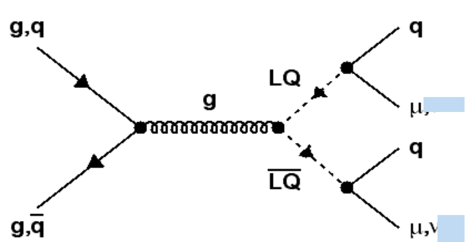


SM background
Drell-Yan+2jets
Top (dilepton)
QCD/Fakes

Selection

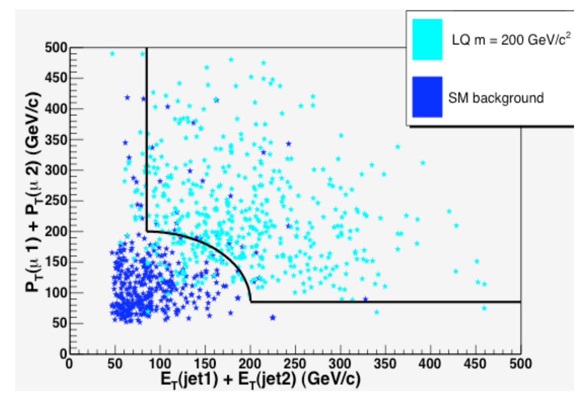
- ✓ 2 electrons (CC,CF) E_T > 25 GeV
- ✓ 2 jets, E_T(j1) > 30 GeV, E_T(j2) > 15 GeV
- ✓ Z Veto (76 < $M_{\mu\mu}$ < 110) GeV
- ✓ **Electrons/Jets: $E_T^{\,j1(e1)} + E_T^{\,j2(e2)} > 85$ GeV**
- ✓ **$\left((E_T(j_1) + E_T(j_2))^2 + (E_T(e_1) + E_T(e_2))^2 \right)^{1/2} > 200$ GeV**



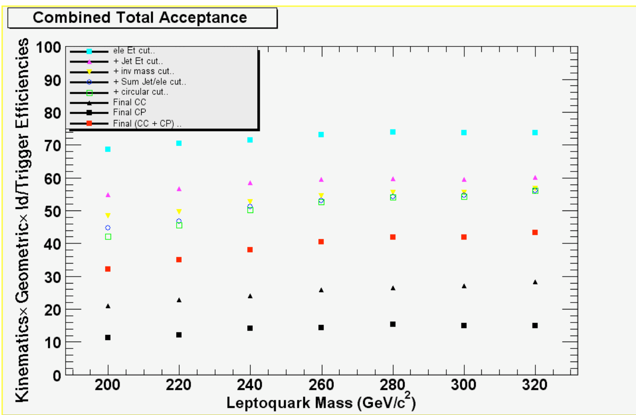


Selection

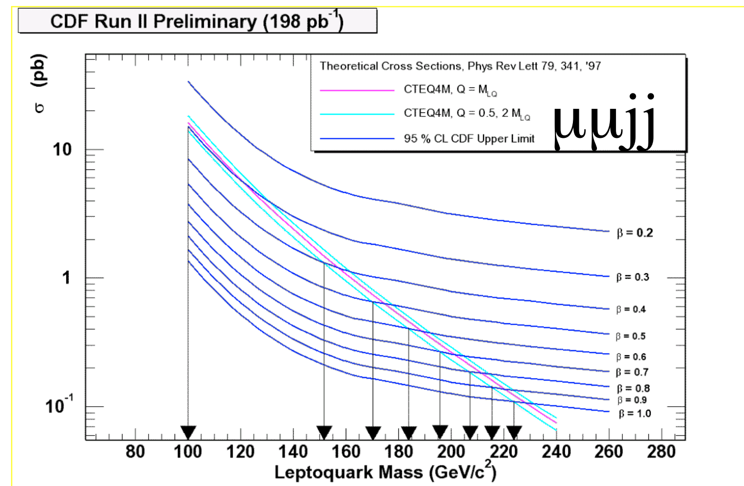
- ❖ 2 muons with P_T > 25 GeV
- ❖ 2 jets with E_T(j1,j2) > 30,15 GeV
- ❖ Dimuon Mass Veto:
  - ❖ 76 < $M_{\mu\mu}$ < 110, $M_{\mu\mu}$ < 15 GeV
- ❖ $E_T(j_1) + E_T(j_2) > 85$ GeV and $P_T(\mu_1) + P_T(\mu_2) > 85$ GeV
- ❖ $\left((E_T(j_1) + E_T(j_2))^2 + (P_T(\mu_1) + P_T(\mu_2))^2 \right)^{1/2} > 200$ GeV

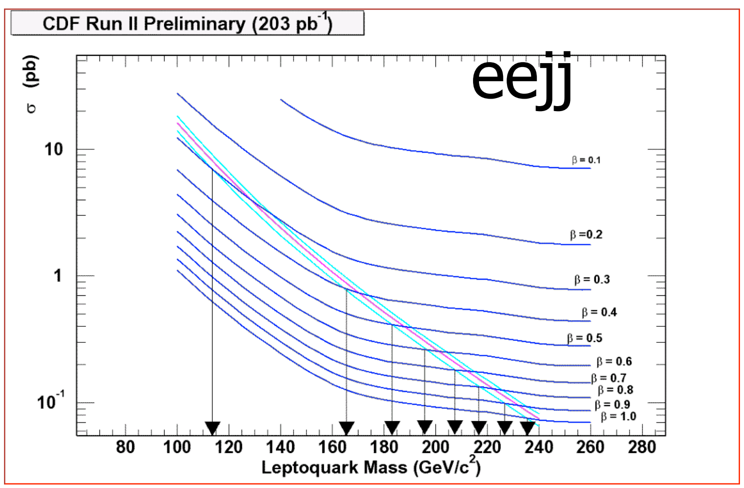


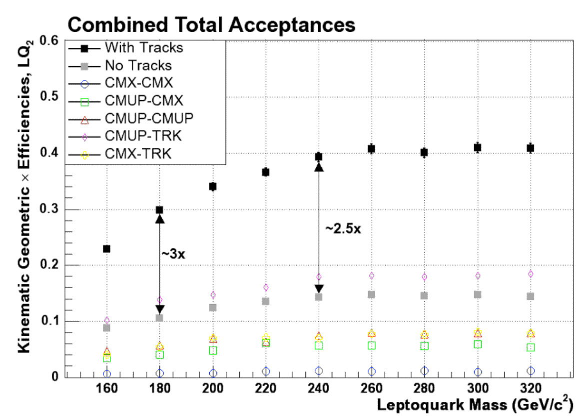
Search for LQ in dileptons + jets (II)



Exclude at 95% CL M_{LQ}<224 GeV/c^2 for β = 1.0

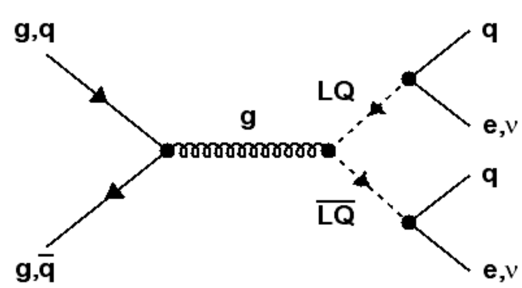






Exclude at 95% CL M_{LQ}<235 GeV/c^2 for β = 1.0

Search for LQ in lepton + MET + jets

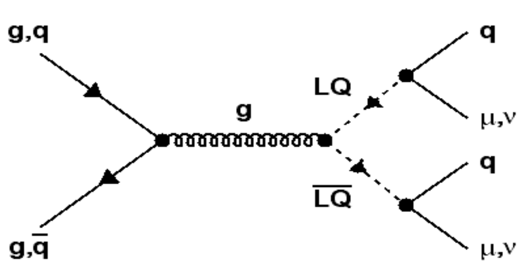


Selection

1central electrons with E_T > 25 GeV
MET > 60 GeV
Veto on 2nd electron, central loose or Plug
2 jets with E_T > 30 GeV
$\Delta\phi$ (MET-jet) > 10°
E_T(j1) + E_T(j2) > 80 GeV
M_T(e-ν) > 120
LQ mass combinations

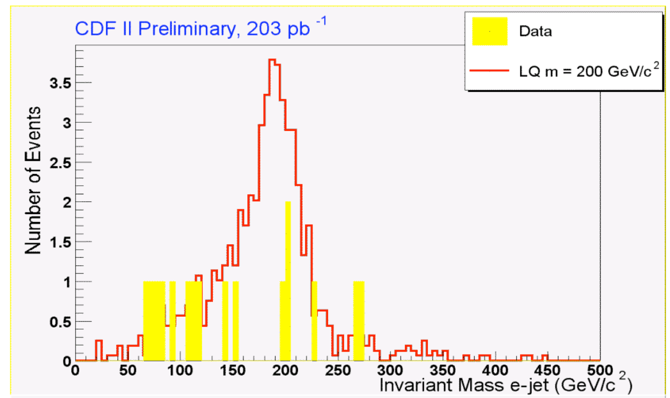
SM background

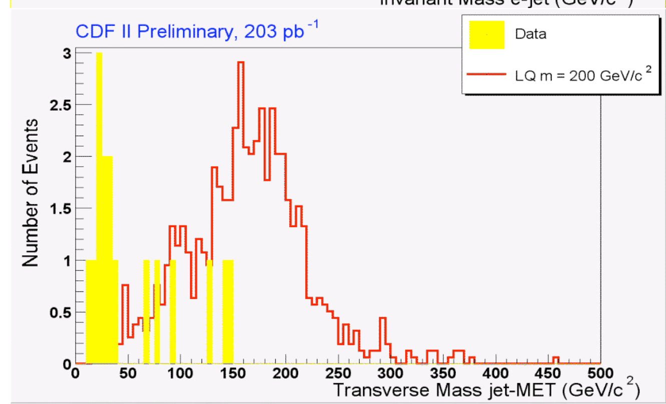
- W +2jets
- Top (l + jets and dilepton)
- QCD/Fakes



Selection

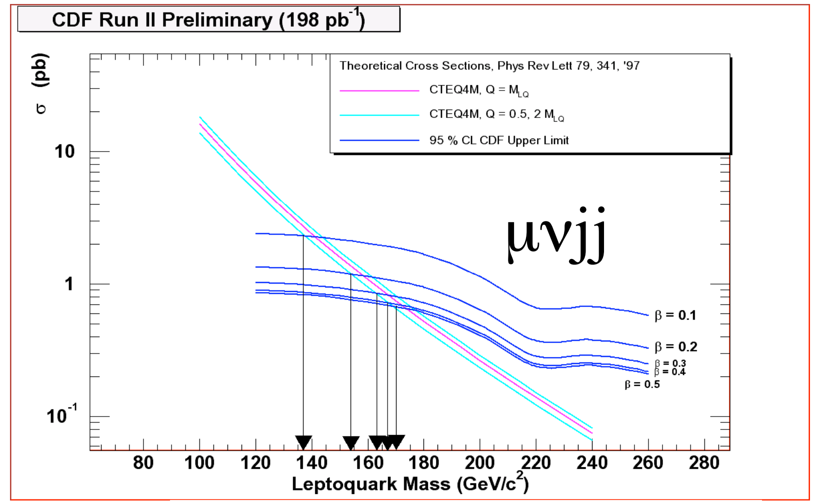
Z veto (tight/loose pair)
No 2nd muon (CMUP, CMX, or stubless)
$P_T(\mu)$ > 25 GeV
$\not{E}_T$ > 60 GeV
2 jets, @ E_T>30GeV
$\Delta\phi(\mu,\not{E}_T)$<175°, $\Delta\phi(\not{E}_T$,jets)>5°
E_T(jet1)+E_T(jet2) > 80 GeV
$M_T(\not{E}_T$,Muon) > 120 GeV/c²
Mass Cut

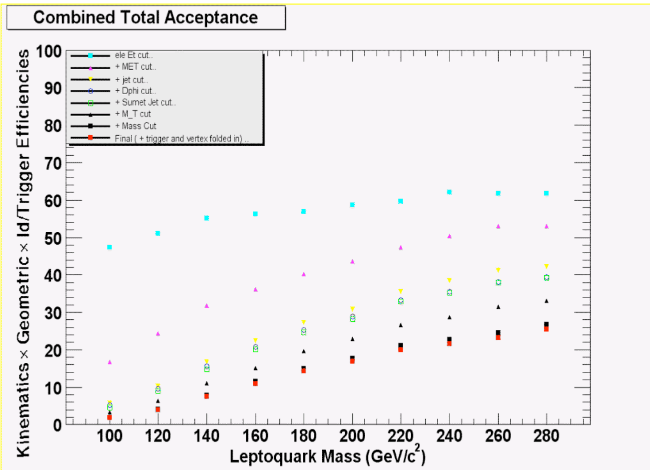


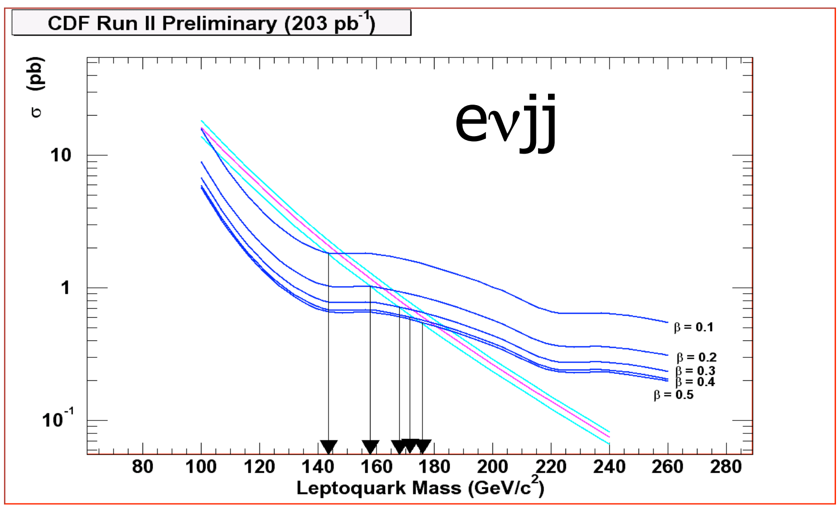


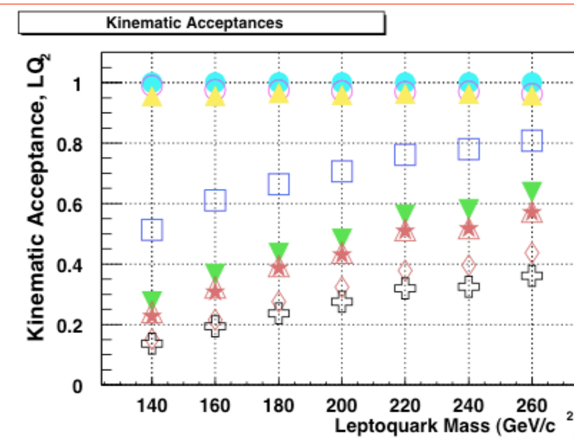
Search for LQ in lepton,MET + jets (II)

Exclude at 95% CL M_{LQ}<170 GeV/c^2 for β = 0.5









Exclude at 95% CL M_{LQ}<176 GeV/c^2 for β = 0.5

Combined Limits

Joint likelihood formed from the product of the individual channels likelihood.
The searches in the dileptons and lepton + MET channels use common criteria and sometime apply the same kind of requirements (for example on lepton identification) so the uncertainties in the acceptances have been considered completely correlated (which gives the most conservative limit).
When calculating the limit combination including also the νvjj channel the uncertainties in the acceptances have been considered uncorrelated.A correlation factor of 0.5 has also been considered (no difference)

$$\sigma_{LIM} = N_{LIM}/(\varepsilon_{average} \times L)$$

$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + \beta^2\varepsilon(ee \text{ as } e\nu))$ for the 2 channels case and
$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + (1-\beta)^2\varepsilon(\nu\nu jj) + \beta^2\varepsilon(ee \text{ as } ev))$ for the 3 channels case.

TABLE III: 95% C.L. lower limits on the first generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[7] ($eejj$) Run I ($\sim 120 pb^{-1}$) is also given.

β	ee jj	$e\nu jj$	$\nu\nu jj$	Combined	CDF Run I
0.01	-	-	116	126	-
0.05	-	-	112	134	-
0.1	-	144	-	145	-
0.2	-	158	-	163	-
0.3	114	167	-	180	-
0.4	165	174	-	193	-
0.5	183	176	-	205	-
0.6	197	174	-	215	-
0.7	207	167	-	222	-
0.8	216	158	-	227	-
0.9	226	144	-	231	-
1.0	235	-	-	236	213

TABLE III: 95% C.L. lower limits on the second generation scalar leptoquark mass (in GeV/c^2), as a function of β.The limit from CDF[4] ($\mu\mu jj$) Run I ($\sim 120 pb^{-1}$) is also given.

β	$\mu\mu$ jj	$\mu\nu jj$	$\nu\nu jj$	Combined	CDF Run I
0.01	-	-	114	125	-
0.05	-	-	110	133	-
0.1	-	137	-	143	-
0.2	-	155	-	157	-
0.3	100	162	-	176	-
0.4	152	168	-	200	-
0.5	171	170	-	208	-
0.6	184	168	-	213	-
0.7	196	162	-	217	-
0.8	206	155	-	221	-
0.9	215	137	-	224	-
1.0	224	-	-	226	202

This analysis

Our intent is to update the 200 pb^{-1} results with the current luminosity - including P19 we could use ~4 fb^{-1}

Several things have changed since the previous analyses

- Ntuple format - we used eN ntuples previously but the package is not maintained anymore (plus we did the ntuple skimming)
  - we are using TopNtuple now
- MC Release - our previous analysis was based on gen5 MC
  - We have regenerated the signal samples with 6.1.4mc and recalculated our signal efficiencie
  - We are also using the Top group W+jets and ttbar samples generated with 6.1.4
- These are the major changes, essentially in the infrastructure

Plans

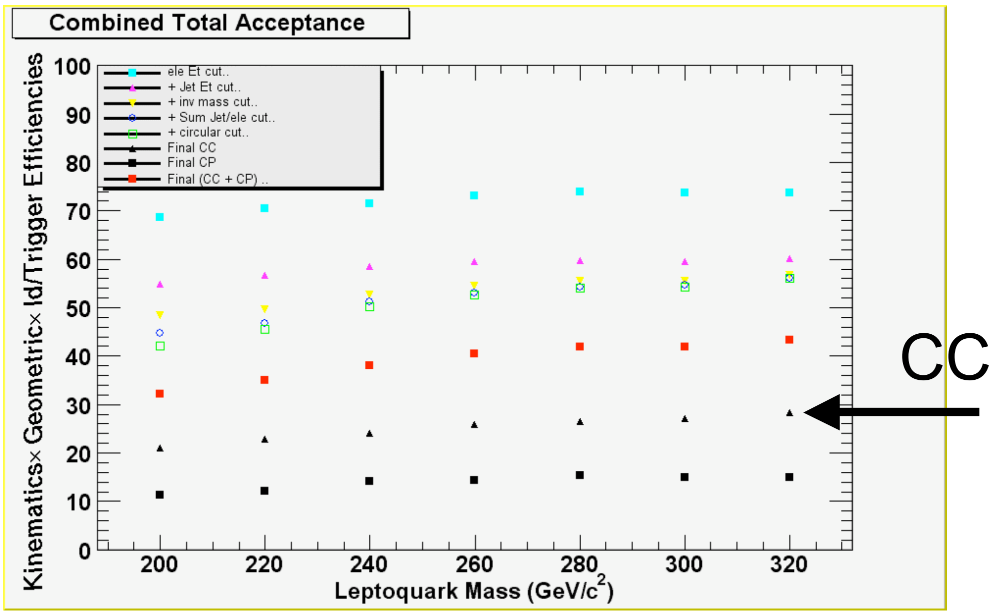
- We intend to update the 200 pb^{-1} analyses with 4 fb.
- We are starting with 1st generation LQ decaying into eeqq
- We are planning to produce updated limits for eeqq, $e\nu qq$, $\mu\mu qq$ and $\mu\nu qq$ channels and combine the results with the $\beta = 0$ analysis into a final CDF paper

Status

- We have started with 1st generation LQ→eeqq
  - Central-central electrons for now
  - We ran a simplified analysis last Spring with a undergrad student at Tufts, Gabriel Dunn
  - Using about twice the luminosity of the published analysis we obtained an already better limit.
    - Simplified analysis:
      - we used the same signal efficiencies as from the published analysis
        - We checked that the on the same masses we were obtaining the same values
      - We re-evaluated the Z+2 jets background as well as ttbar using the new MC
        - We did not use the mcfm x-sections for Z+jets
      - We did not re-calculated the QCD fake contribution but used an estimate from the previous analysis
      - We applied a large stat+sys error in the calculation of the limit

Gabe's thesis result

Signal



M(LQ)	ε	Relative uncertainty	N limit
200	0.207	0.14	7.438
240	0.233	0.12	7.306
260	0.234	0.10	7.201
280	0.243	0.09	7.15

The relative uncertainty on the signal efficiency is taken from the 200pb analysis (stat + sys)

We recalculated the signal efficiencies with the new MC and found them in excellent agreement with the 5.x numbers

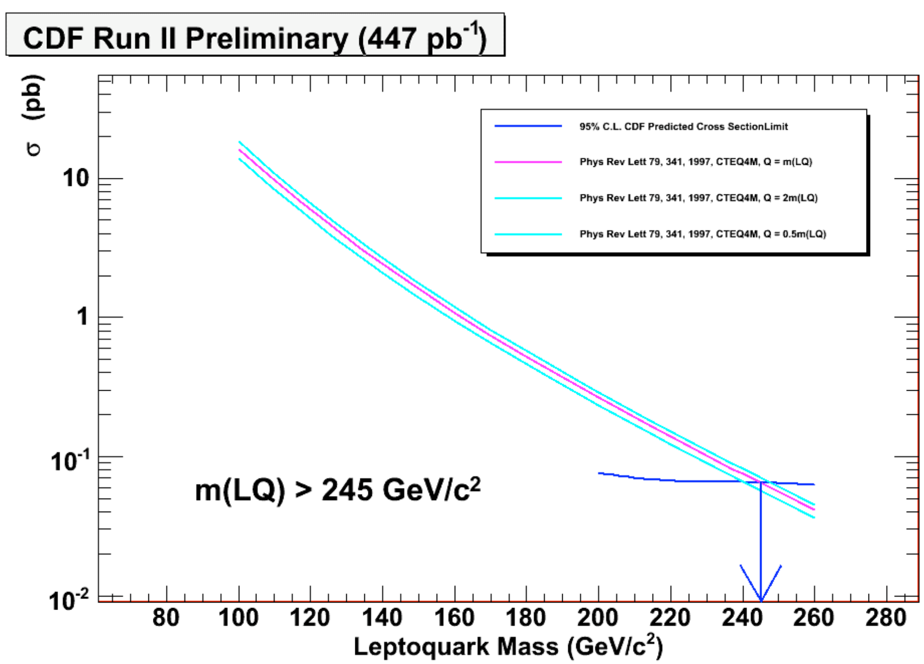
Gabe's thesis result (con't)

Background

- Z+jets background:
  - 4 MC samples were used corresponding to different Z mass regions:
    - $8 < M(Z) < 20$ GeV/c^2 ($\sigma = 6.98$ pb)
    - $20 < M(Z) < 75$ GeV/c^2 ($\sigma = 1.61$ pb)
    - $75 < M(Z) < 105$ GeV/c^2 ($\sigma = 3.47$ pb)
    - $105 < M(Z) < 600$ GeV/c^2 ($\sigma = 0.117$ pb)
- After applying all the analysis cuts the number of predicted Z+2jets in the LQ signal region is 0.83 ± 0.16 for 447 pb^{-1} statistics (we used the alpgen x-section and we want to use mcfm in the future).
- The background from ttbar was calculated using a ttbar MC: the number of expected events is $\sim 0.33 \pm 0.05$
- The background from QCD fakes is not calculated at this time (extrapolating from the published analysis it is assumed to be of ~2 events)

A very preliminary limit

- We used a very large uncertainty on the background:
  - 50% uncertainty on the number of predicted background (consistent with the 200 pb^{-1} analysis)
  - We used bayes to calculate the limit



Number of observed events: 4

$\sigma_{LIMIT} = N_{LIMIT}/(\mathcal{L} \times \varepsilon \times \beta\beta)$

$\beta = 1$

Limit improved of ~10 GeV!

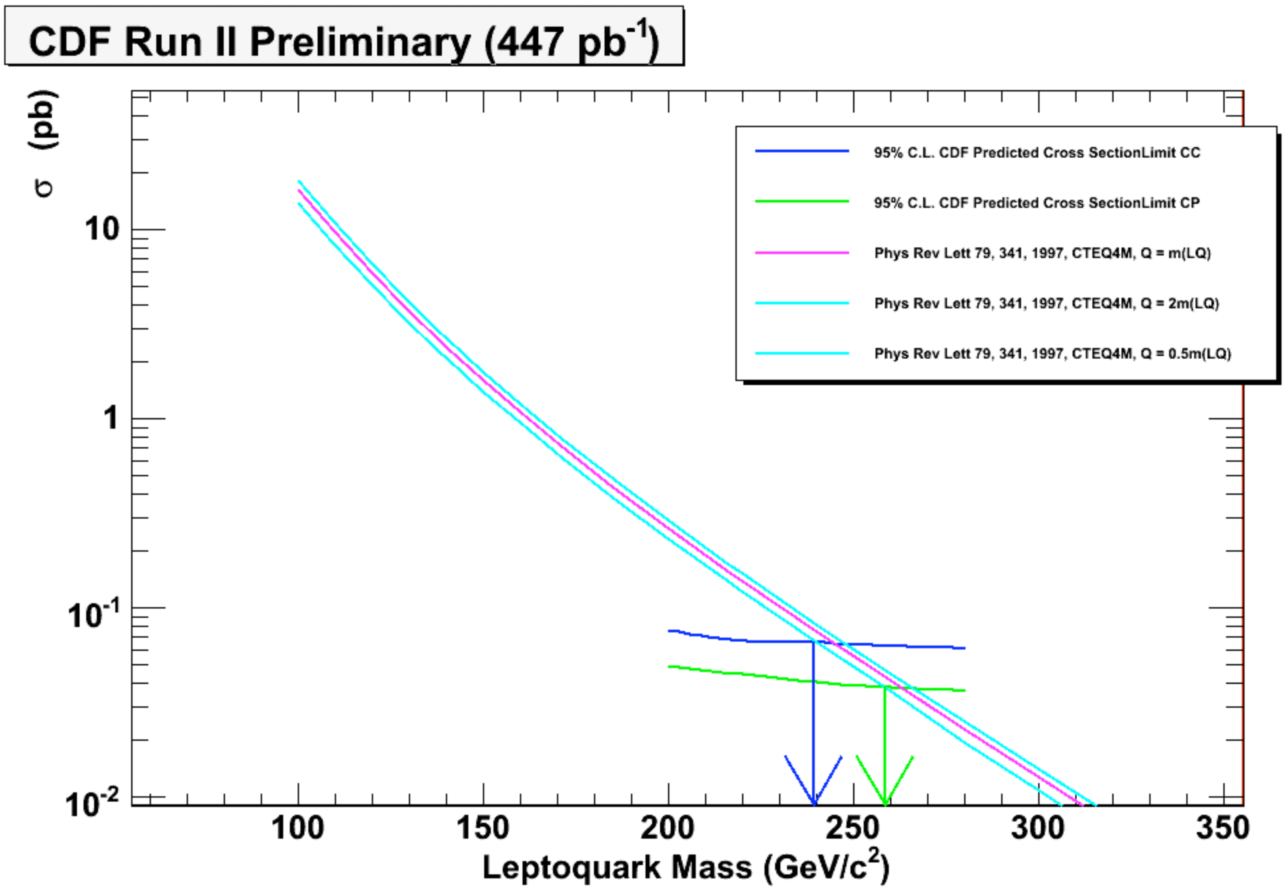
Plans

- 1st generation dilepton analysis needs
  - Acceptance extended to plug ele
    - At the time of the 200pb analysis there were no PHENIX, we used simple plug electrons, it might be an option now
  - Better determination of DY+jets background
    - mcfm x-sections
  - New data-driven QCD fakes determination
  - Updated systematics
  - All data!

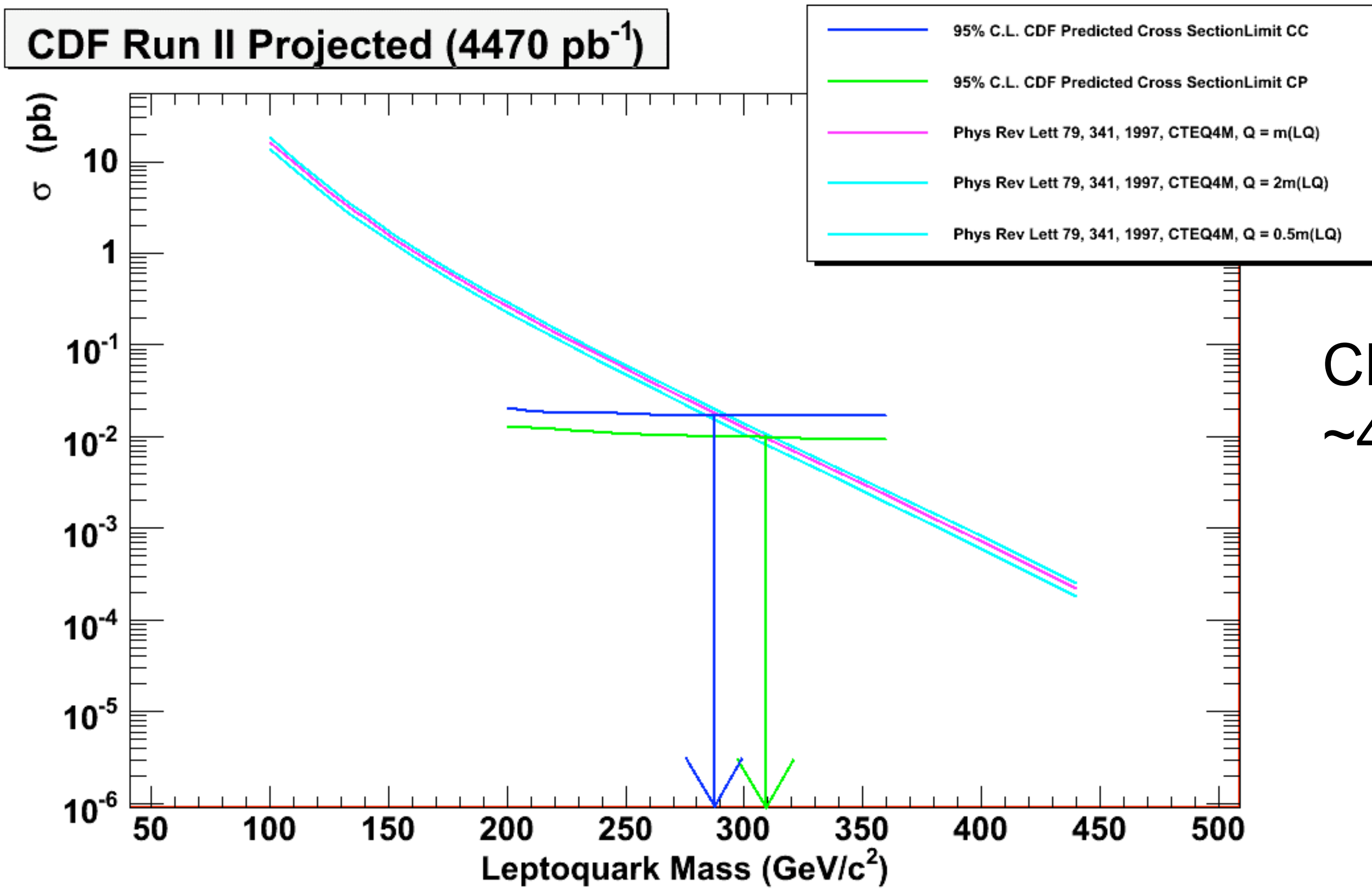
I plan to devote substantial time to try to complete the dilepton analysis by late Spring and the eνqq analysis by Summer. Second generation will follow.

Projections

Adding Plug Electrons



Projections



CP and CC
~4fb